SPA Serial 32539

# *Sensor Performance Optimization Tool (SP◎T)*


**James Richardson, SPA**


**10 – 12 June 2008**

**76th MORS Symposium**
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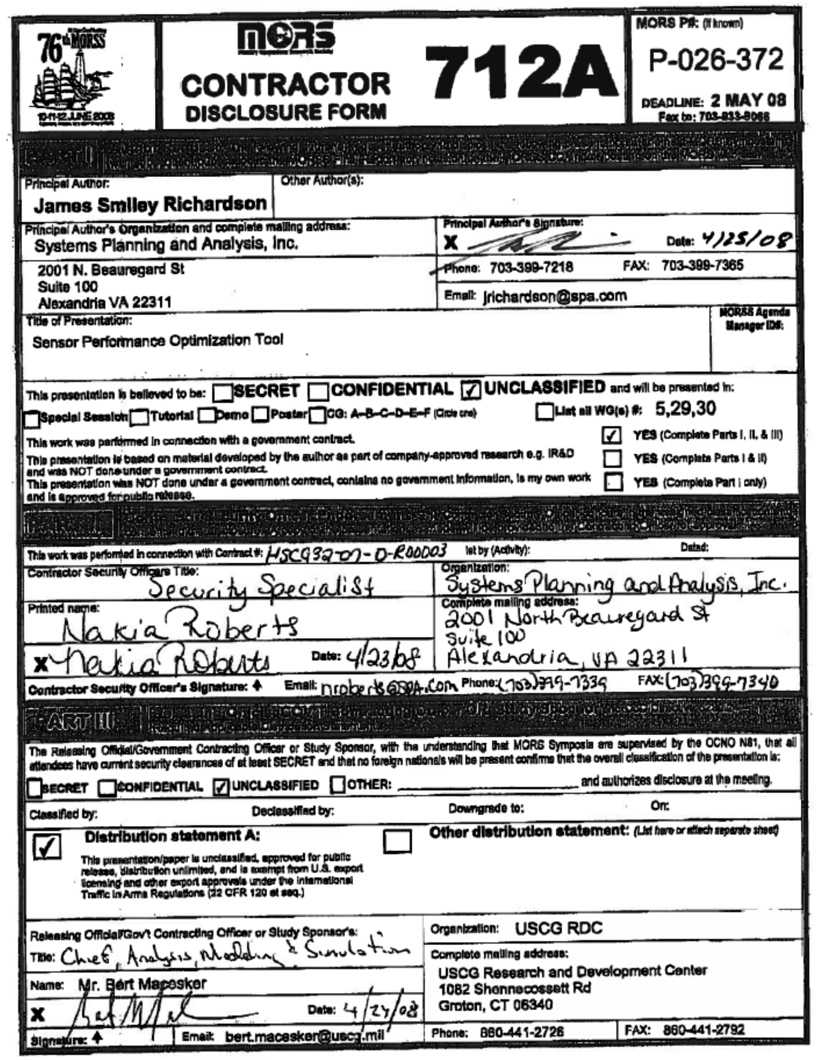

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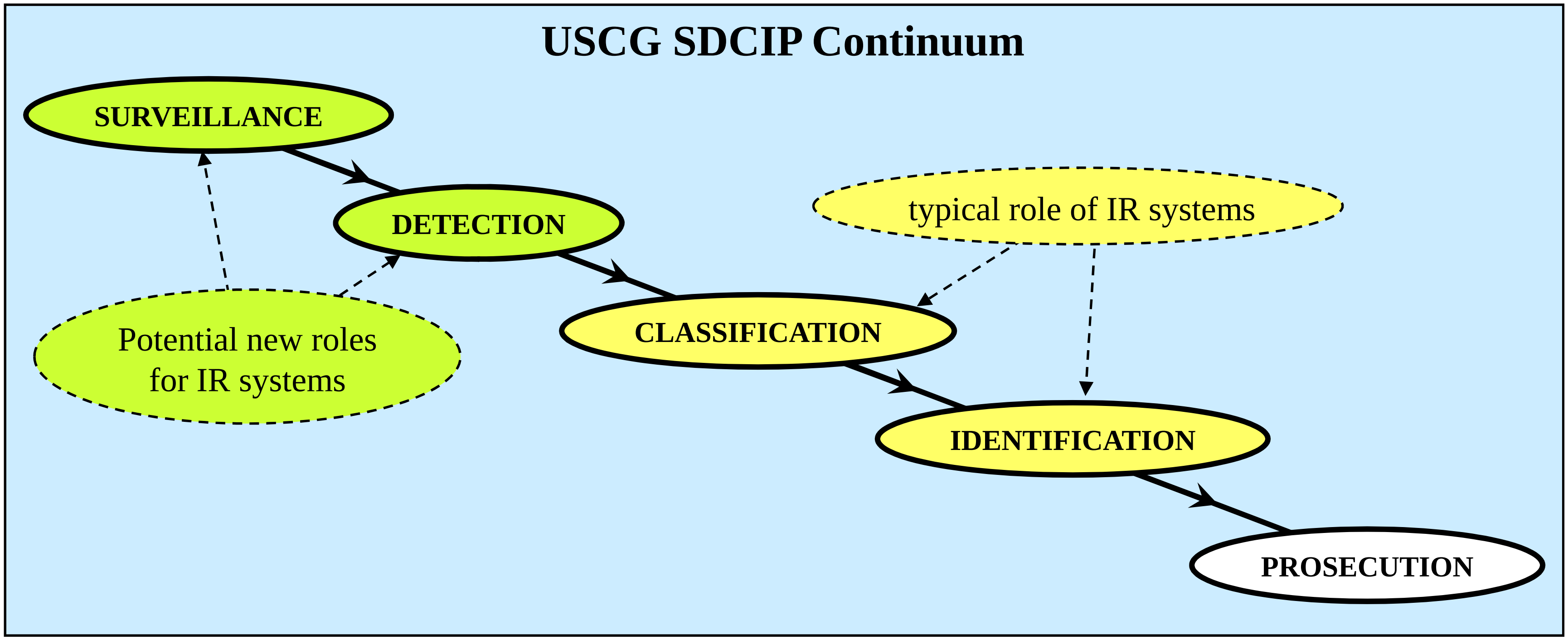
# Schedule of Presentations

- **Tuesday 10 June 2008, 10:30 AM**
  - **WG – 5 Homeland Security and Civil Defense**
- **Wednesday 11 June 2008, 10:30 AM**
  - **WG 29 – Modeling, Simulation and Wargaming**
  - **WG 30 – Operational Environment – Factors, Interactions, and Impacts**

# Introduction

- **Background**
  - **USCG is in the process of acquiring improved infrared (IR) sensor systems for installation on standard rotary-wing platforms.**
  - **Historically, IR sensor systems have not been used for primary detection work.**

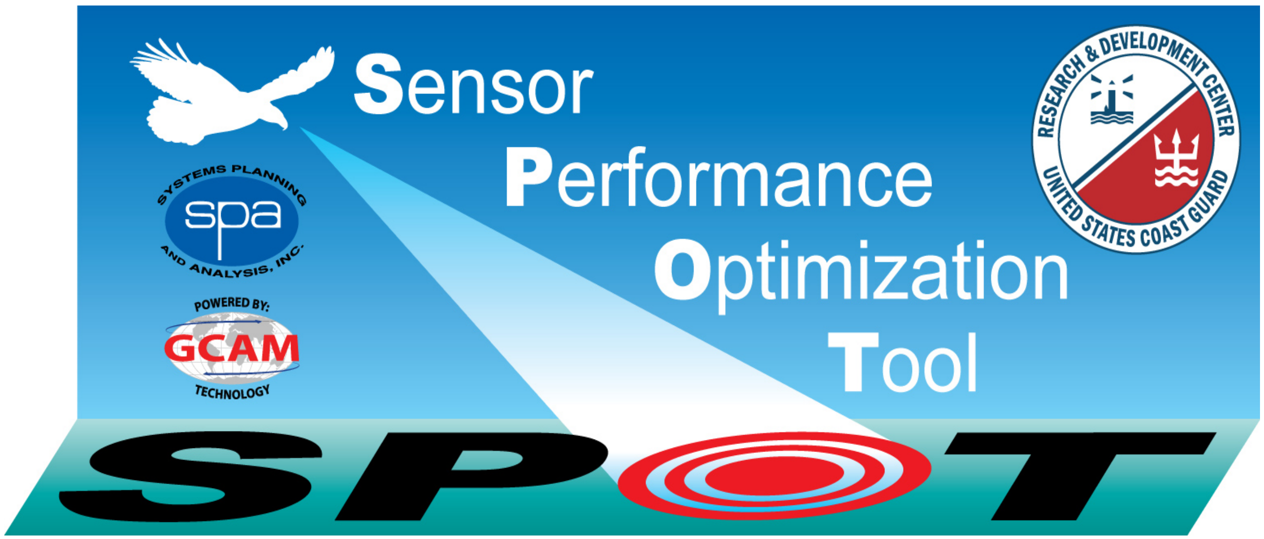



  - **Question remains**

***"How can these high-tech sensors be best employed to assist in obtaining initial detections on hard-to-find targets?"***

# Sensor Performance Optimization Tool (SP◎T)

- **In 2007, collaboration began between the USCG RDC and SPA to develop a software tool that could help analysts and pilots further understand the factors that drive effective searches**




- **The Sensor Performance Optimization Tool is a simulation-based tool that:**
  - **Captures key platform and system performance characteristics**
  - **Visualizes search effectiveness**
  - **Can be used to creates a collection of “best searches” from which analysts and pilots can choose the most operationally feasible search**

# SP◎T Overview

## The Sensor Performance Optimization Tool (SP◎T)

### SPOT.XLS Workbook

- Input specification
- Launch visualization (manual)
- Automation controls
- Results data storage

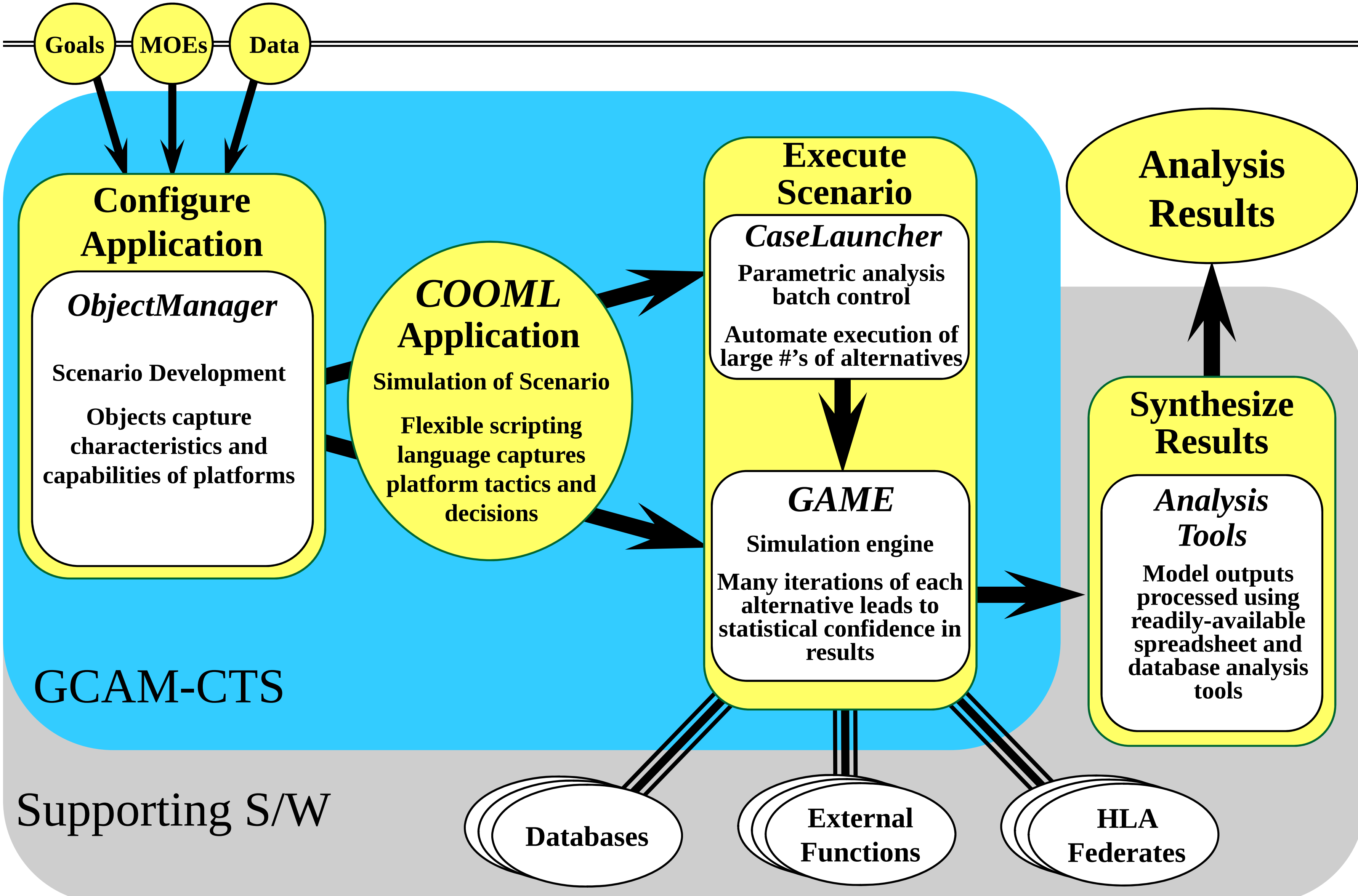
Settings →

← Results

### SP◎T GCAM Application

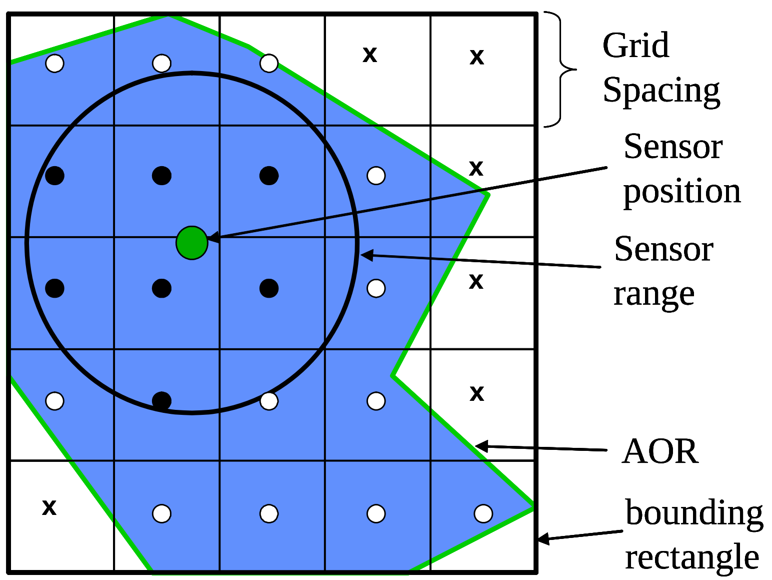
- SP◎T calculations
- animated visualizations
- Video capture for later viewing

# GCAM-CTS Elements

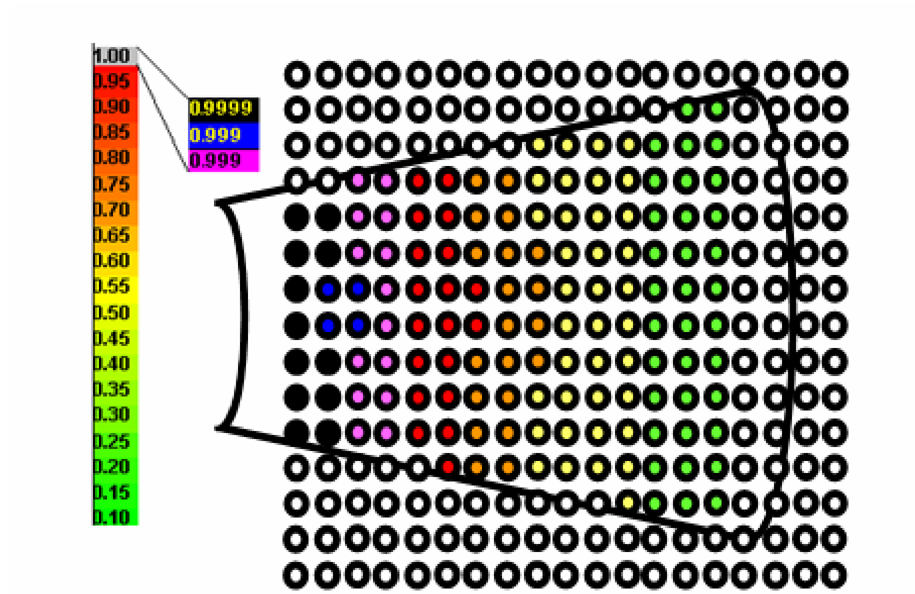


# Visualization with GCAM

- **Capitalize on GCAM's native *Area Coverage* functionality**




● *Contributes to P(det) for this time step*
○ *No contribution this time step*
x *No credit possible (outside of AOR)*



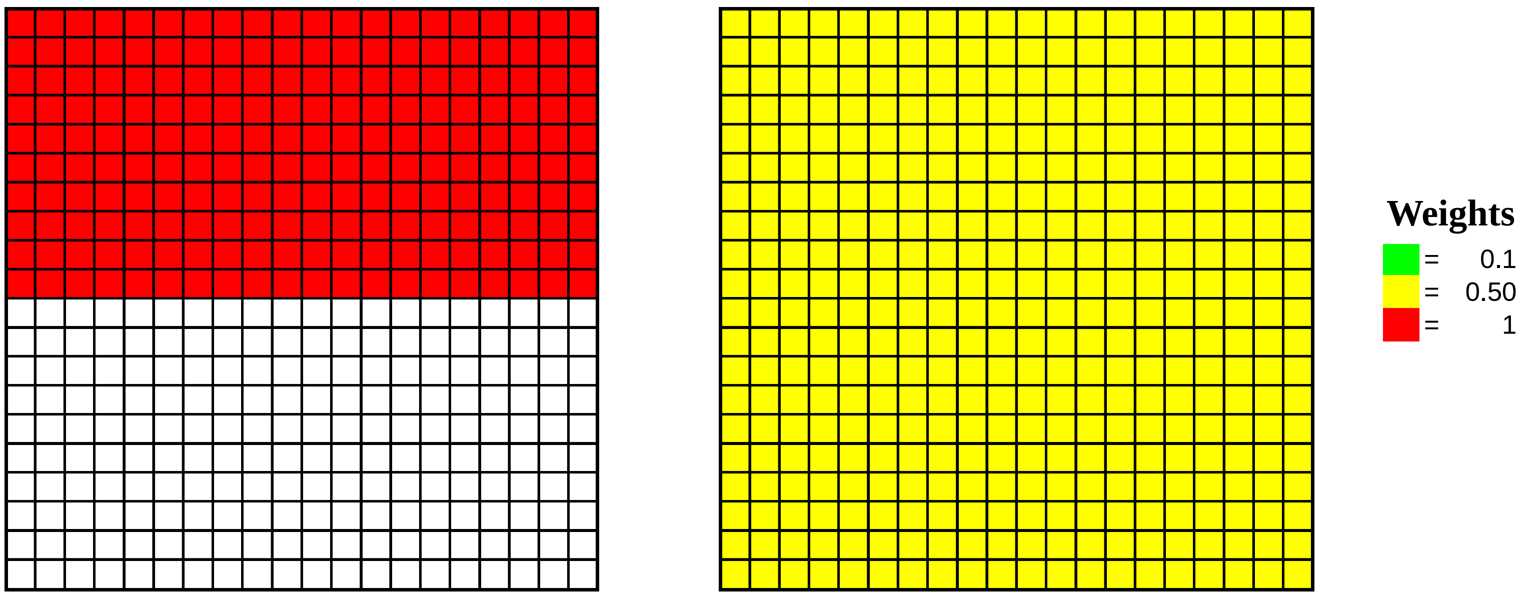
# Probability of Detection

- **Historically, Probability of Detection (POD) is calculated POD = A×Q where,**

  **A = Area Covered – Percentage painted [percentage]**

  **Q = Area Coverage Quality of the Area Covered – Weighted percentage of painted region [percentage]**

- **POD cannot discriminate between the following two searches:**




**POD = 50%** **POD = 50%**

- **What then?**

# SP◎T Score (◎)

$$◎ (A, Q, T : i, j, k, T_0) = \frac{A^i Q^j}{(T/T_0)^k}$$

- Measured Components (computed by the simulation)
  - A = Area Covered – fraction painted [scalar between 0 and 1]
  - Q = Area Coverage Quality – Weighted percentage of Area Painted [scalar between 0 and 1]
  - T = Total Time to complete search pattern [minutes]
- Settings (established by user prior to any study)
  - i = relative value (weight) for the Area (A) factor
  - j = relative value (weight) for the Quality (Q) factor
  - k = relative value (weight) for the Time (T) factor
  - $T_0$ = standard (reference) mission time (usually set to max mission time) – Note: 360 minutes is the standard value.

# Analysis Method

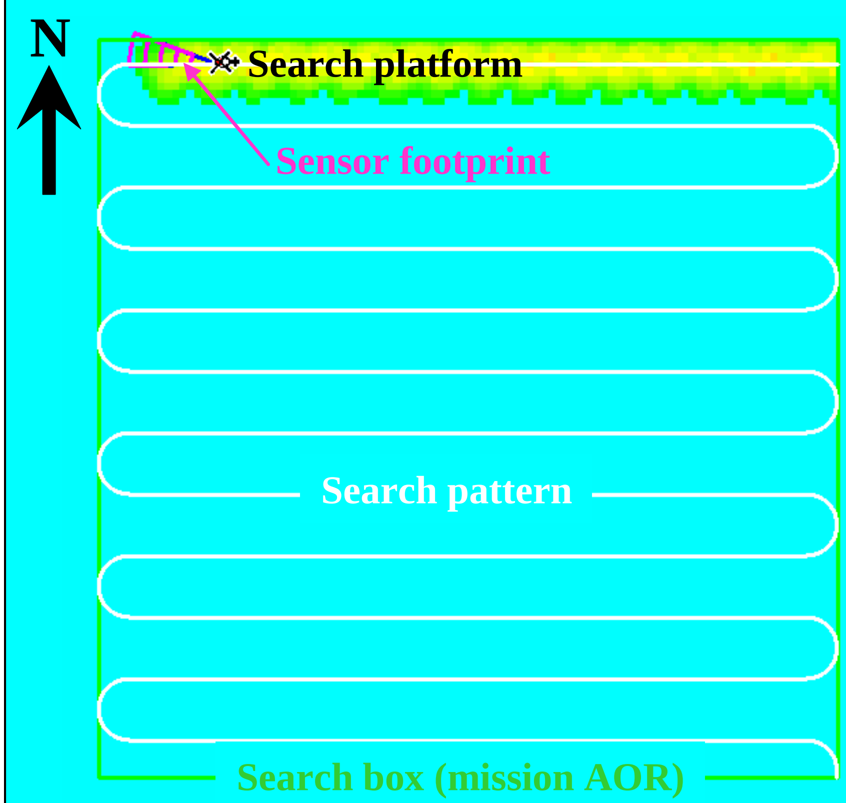
- Analyst use SP◎T's visualization, platform and sensor representation, and optimization capabilities to determine the best and most operationally feasible search pattern.
  - *Scoping Analysis*
    - Use the visualization capabilities to get a feel for the relationship between the controllable inputs and potential solutions.
    - Selects input variables for formal parametric exploration.
  - *Parametric Analysis*
    - Using the automated features of the system to perform planned parametric analysis
  - *Operational Analysis*
    - Select the most practical solutions from among the optimal and near-optimal search configurations based on operational considerations

# An Example

- **Deadliest Catch on Discovery Channel**
  - It is a cold dark night in the middle of the Bering Sea
  - A 20 foot waves are hitting the boat and a crewman is swept overboard
  - The water is 32 degrees and the crewman needs the US Coast Guard
- **The Mission**
  - We are searching for a small target in an AOR is 5 nm by 5 nm
  - Cold Weather Climates and a ceiling of 1500 feet
- **To Prepare for the mission …**
  - How do we select the best flight plan?
  - How should we employ the IR sensor?

# Terms of Reference

## Mission Orientation




**Scenario Specifications**

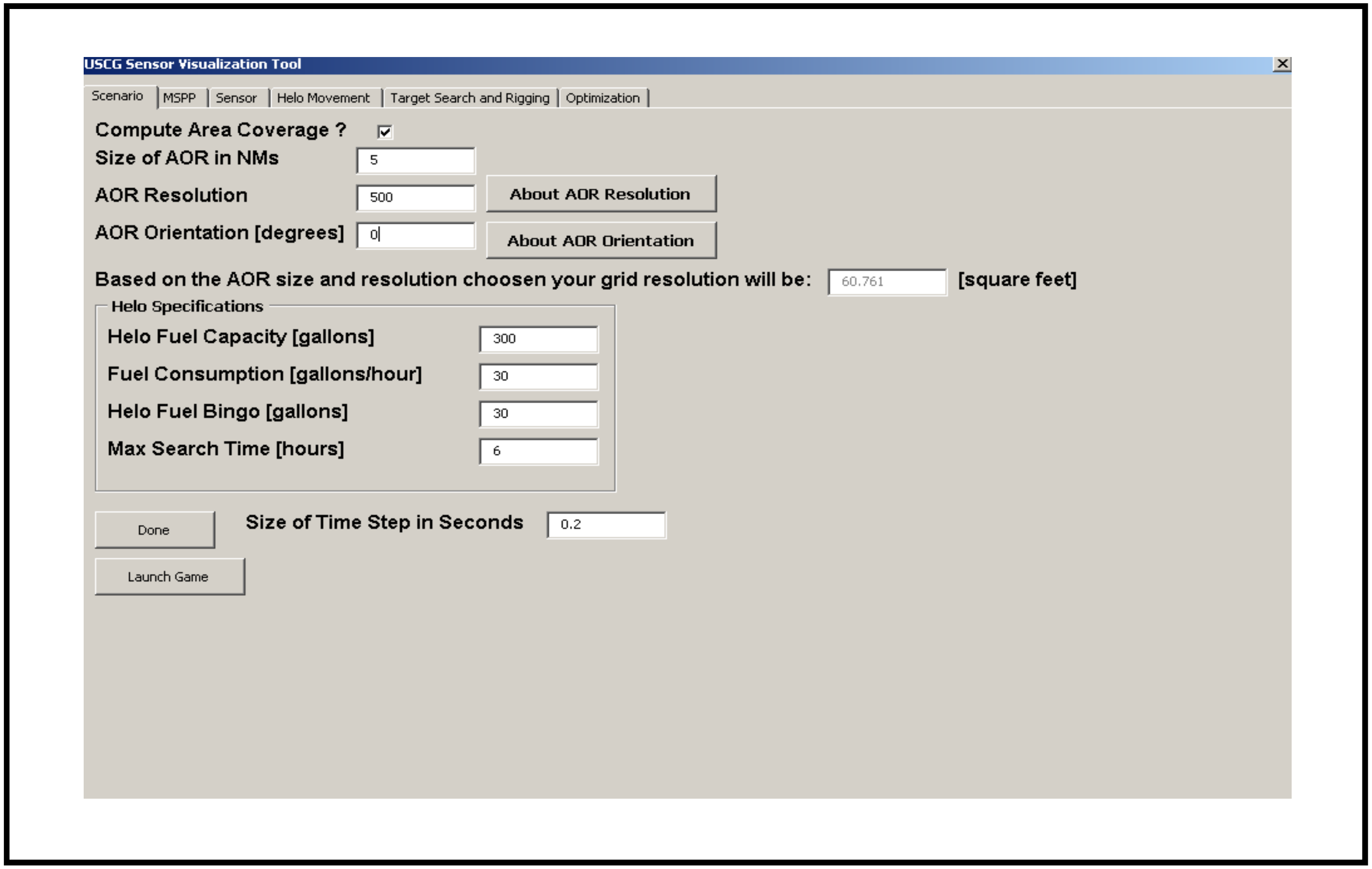
- Target Type
- Environment
  - Location
  - Time of day

## Search Configuration Parameters

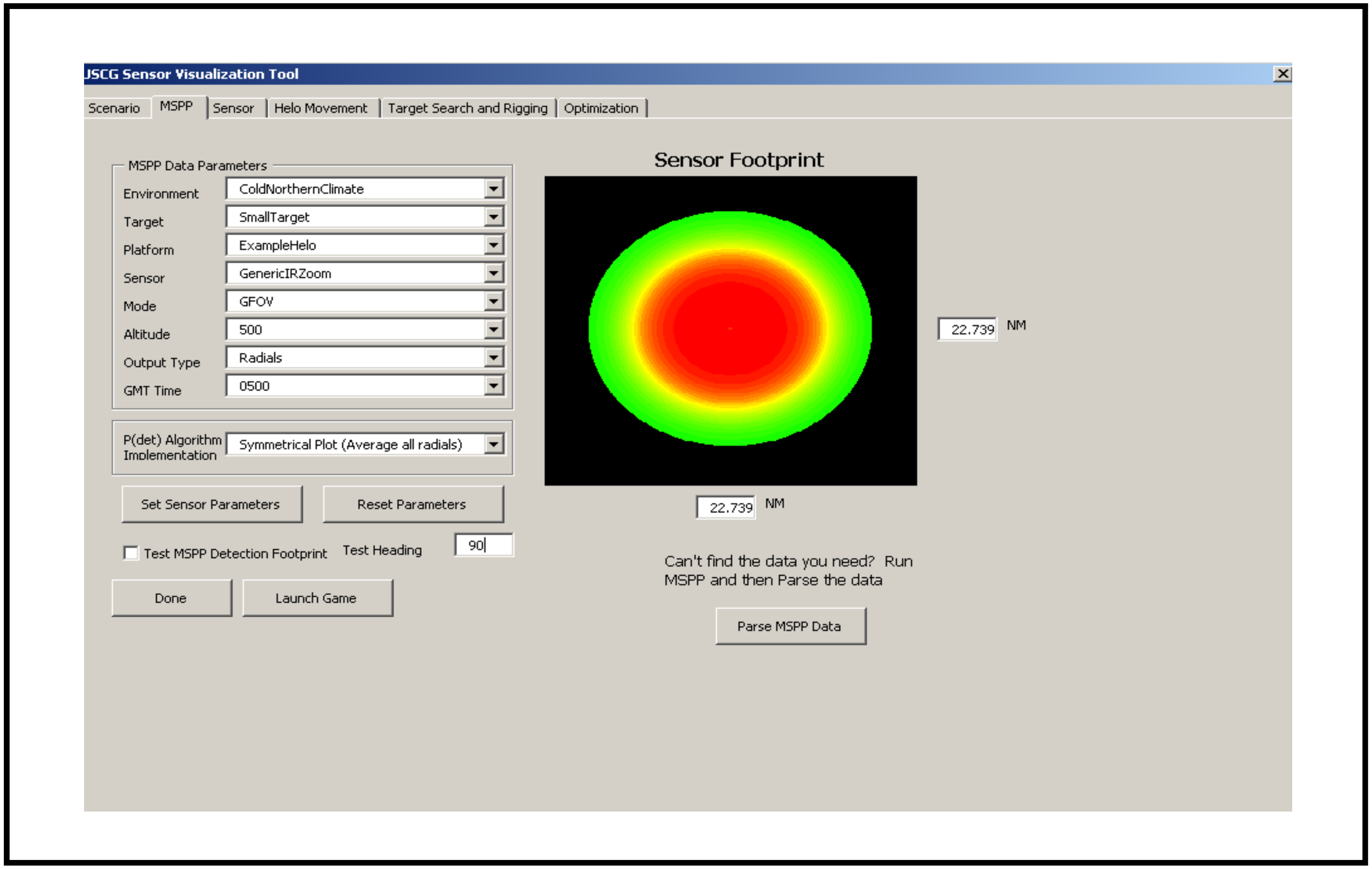
- Platform Settings
  - Speed (knots)
  - Altitude (feet)
  - Search Pattern Selection (e.g. - Ladder)
    - Start position (x , y)
    - Track Length
    - Track Spacing
    - Creep Length
- Sensor Settings
  - Tilt (declination angle, in degrees)
  - Pointing Method (e.g. - Forward Swing)
    - Center point (relative to heading)
    - Maximum swing (each direction)
    - Swing rate (degrees / second)

# Scoping Analysis

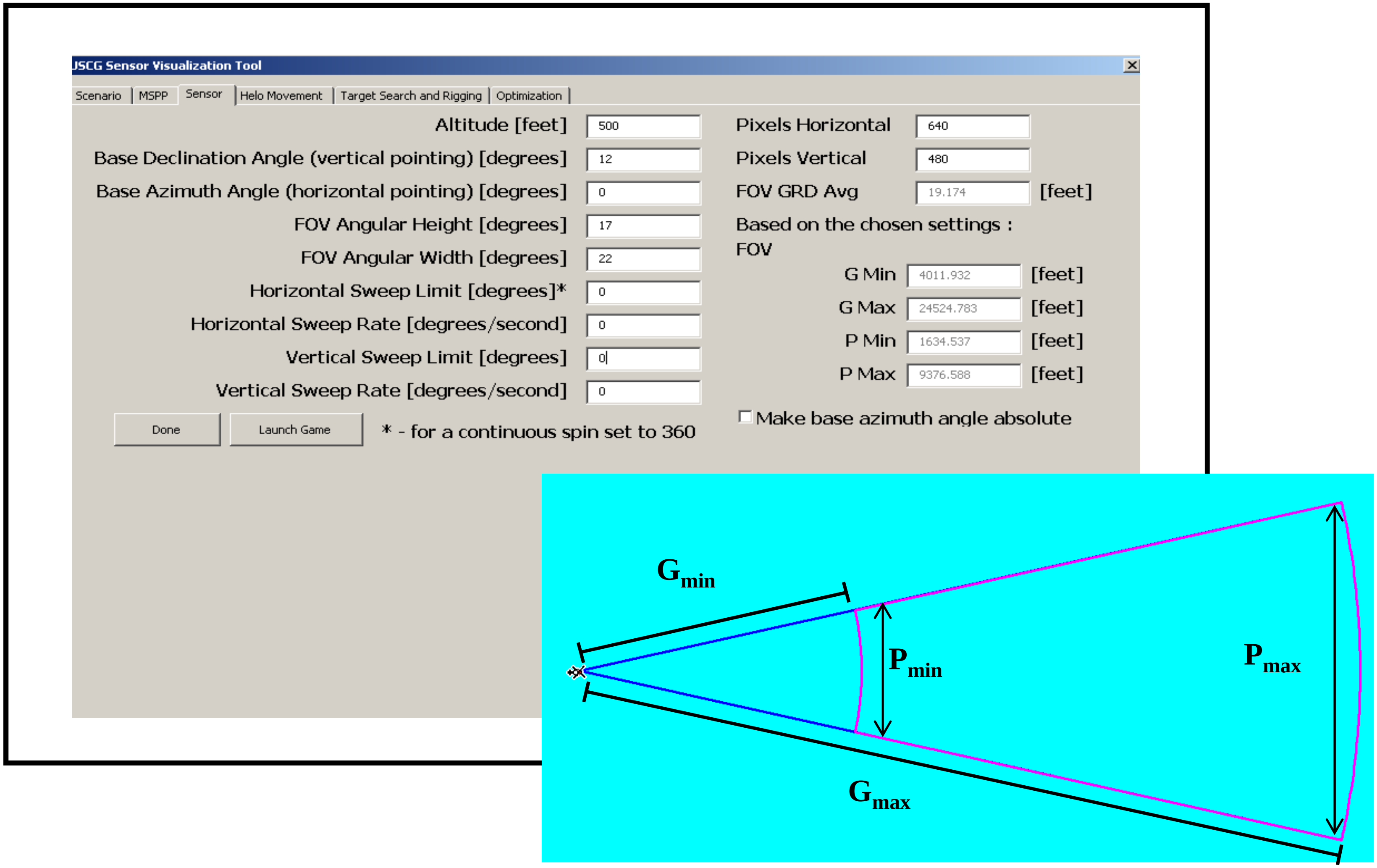
# Enter Scenario Data



# Select Input Data Corresponding to Mission Parameters



# Input Sensor Characteristics and Trial Sensor Utilization Tactics

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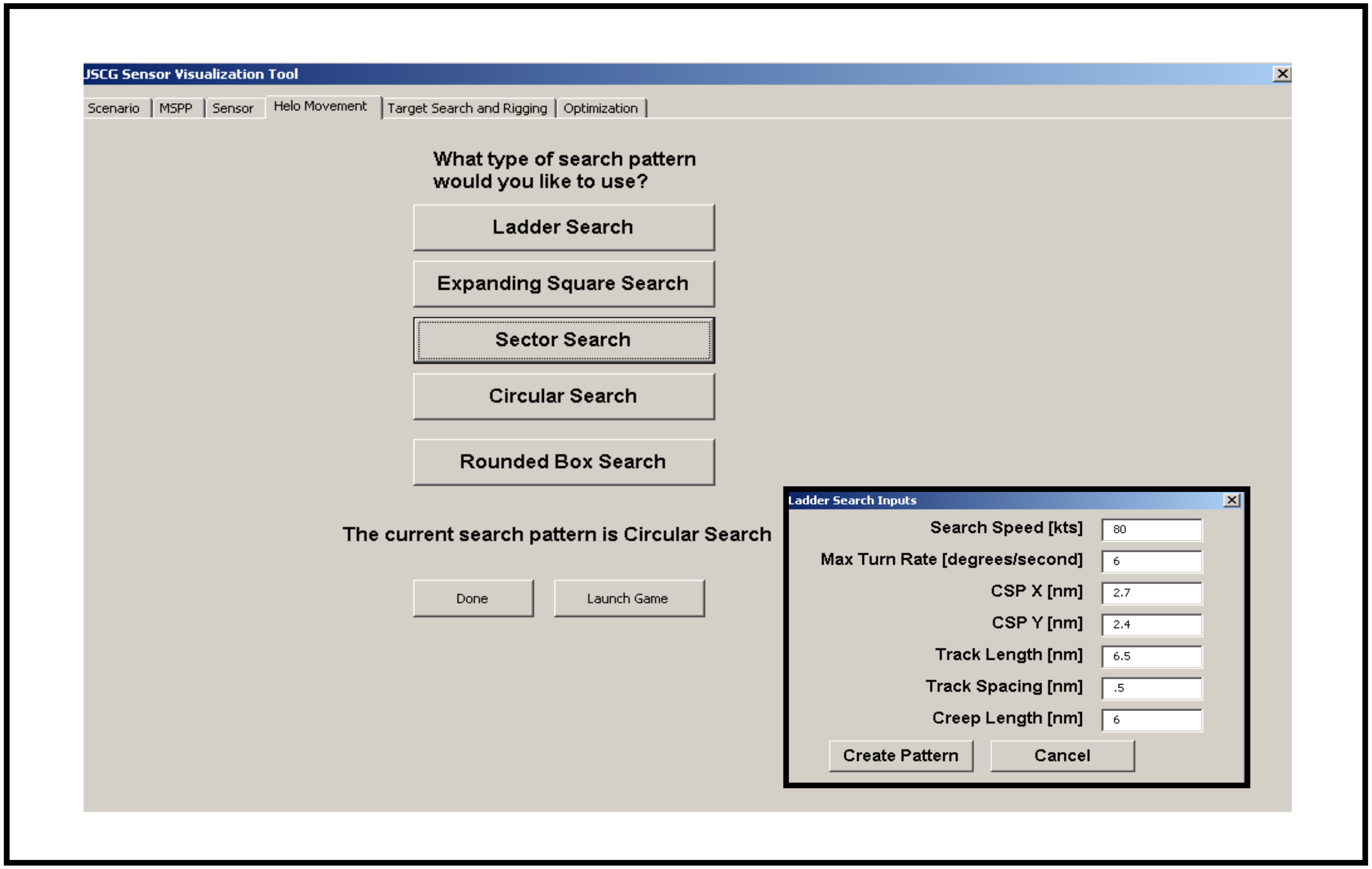
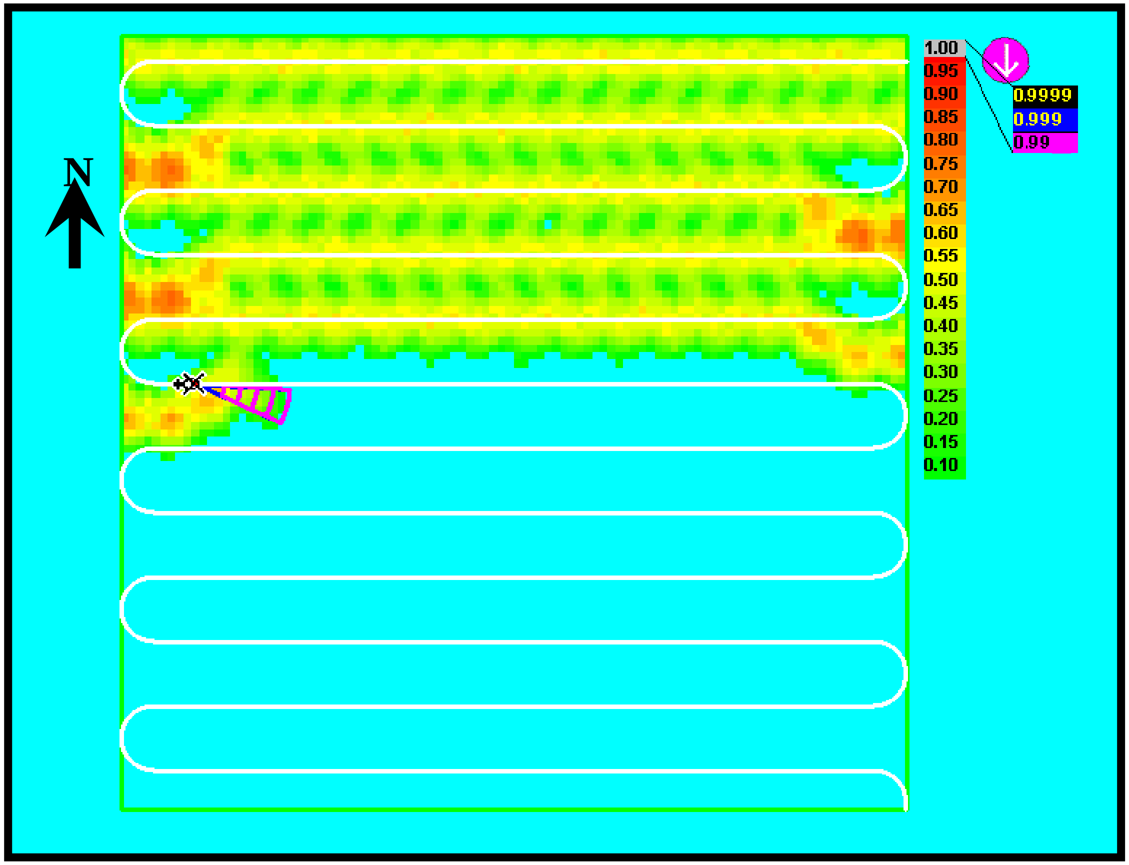
# Input Search Pattern Characteristics



# An Ineffective Search




**5x5 Search Box, Small Target, 14º tilt, 500 feet altitude**
**100 knots, Track Length 5 NM, 0.5 nm track spacing**

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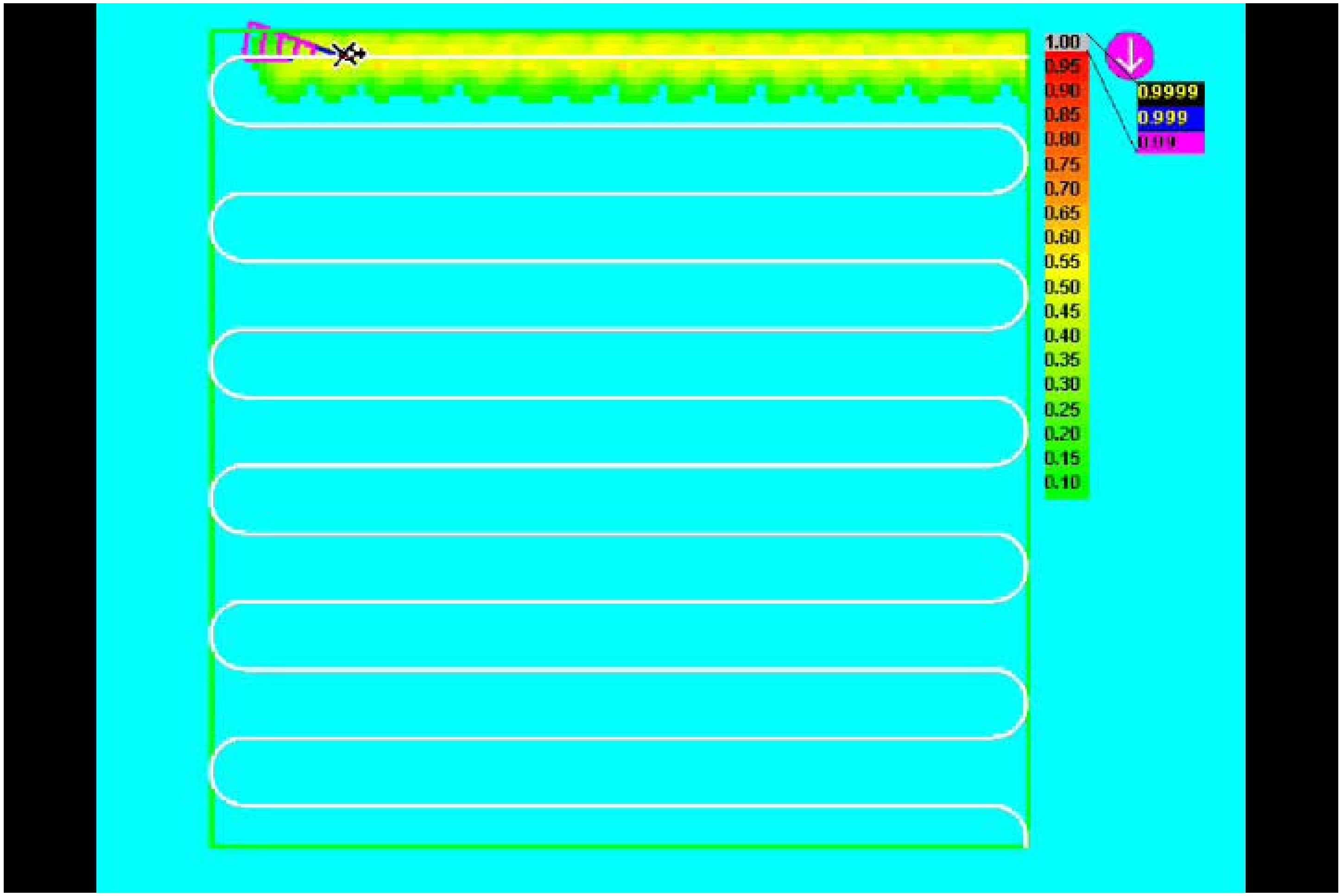
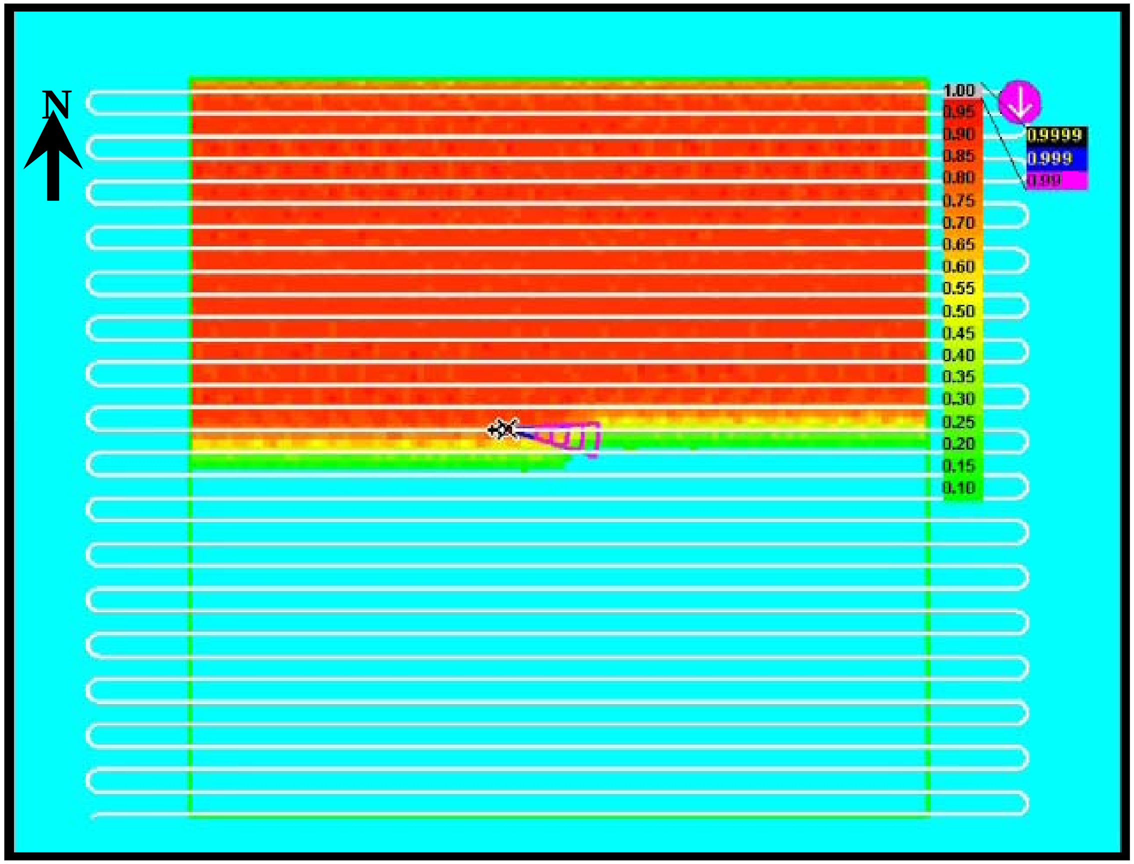
# An Ineffective Search

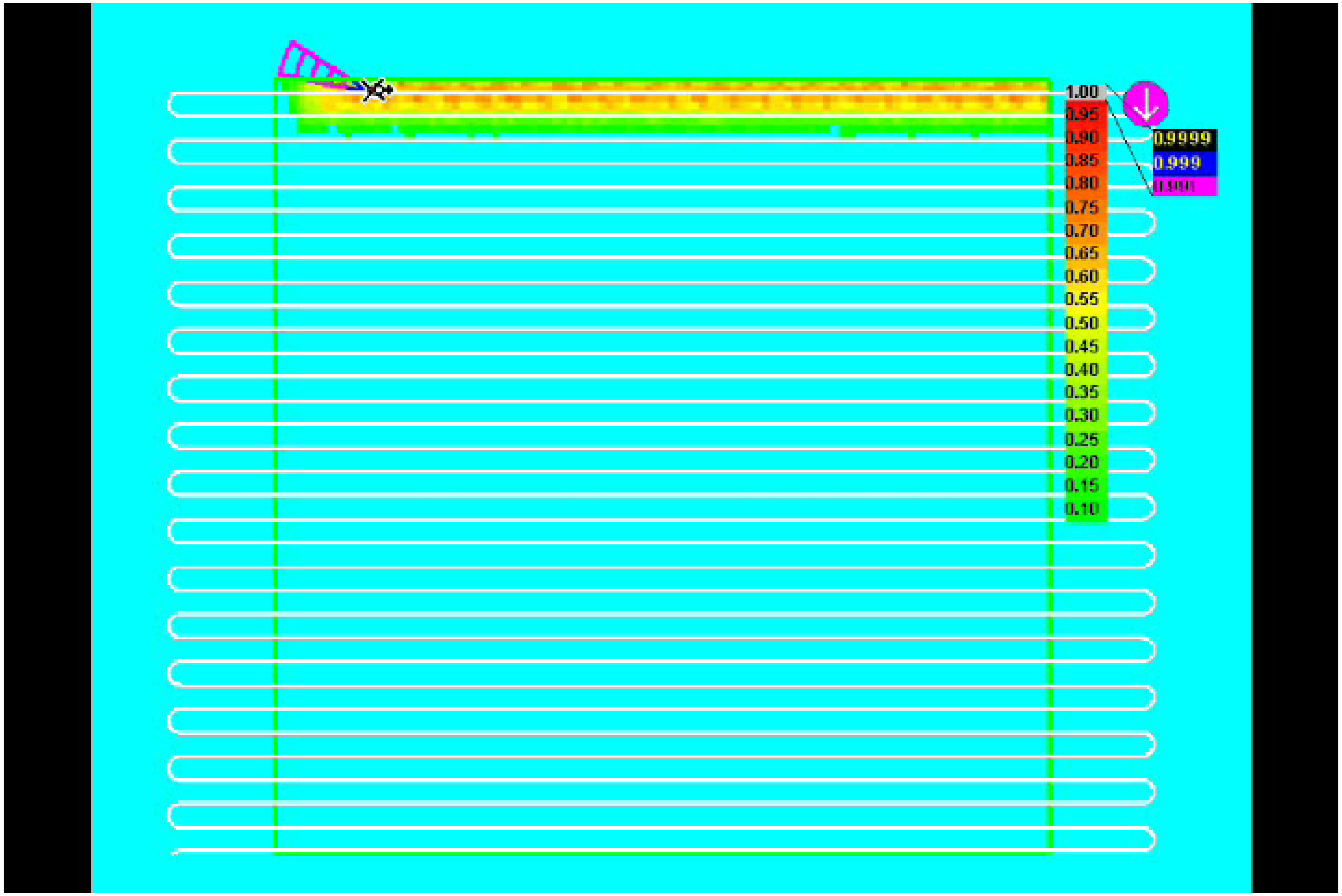


# A Better Search




**5x5 Search Box, Small Target, 14º tilt, 500 feet altitude**
**100 knots, Track Length 5.5 NM, 0.3 nm track spacing**

# A Better Search

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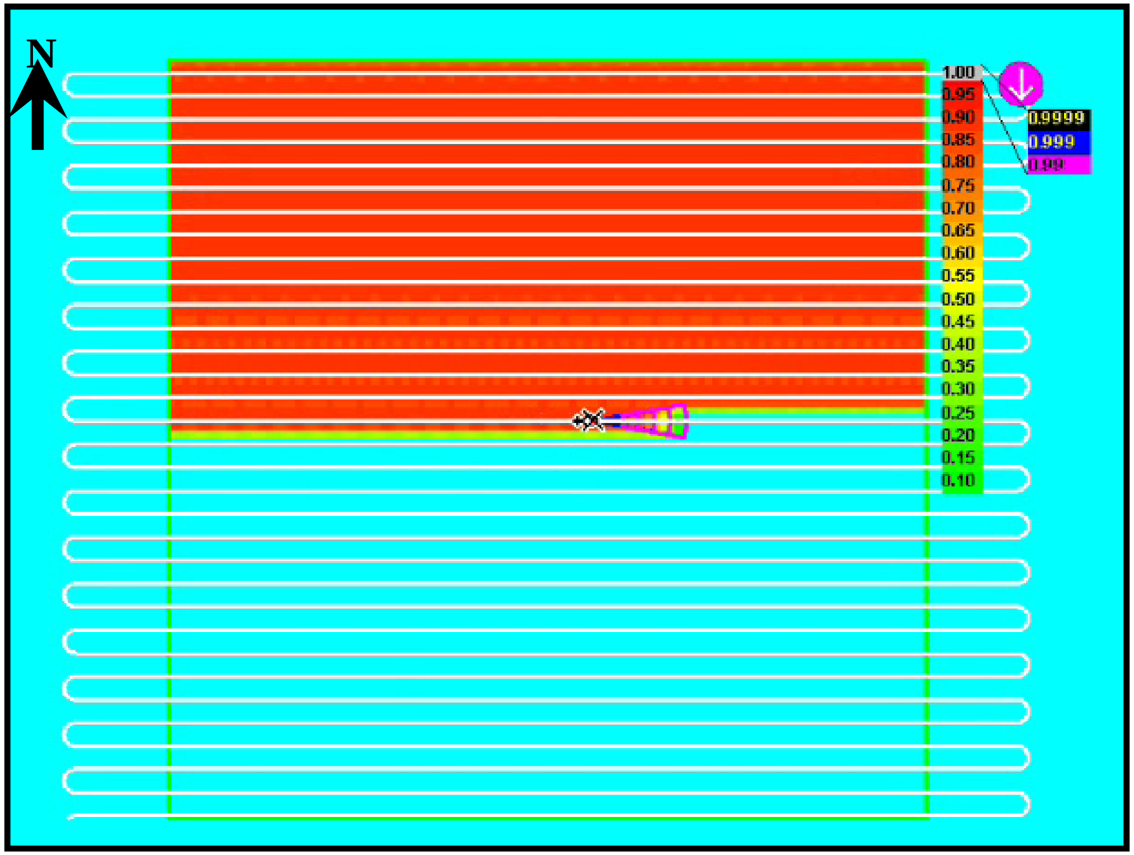
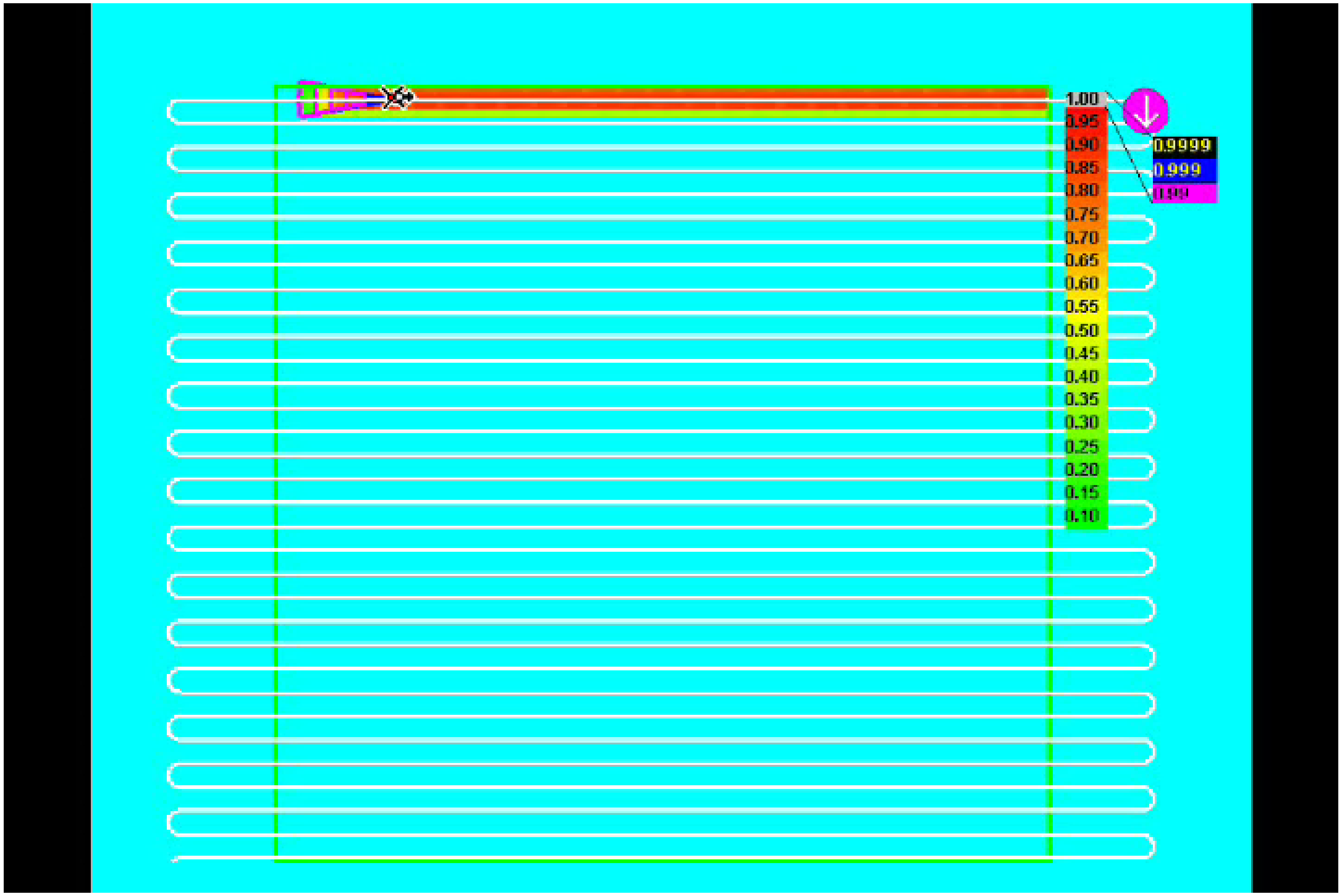
# Good Search (Fixed Forward)

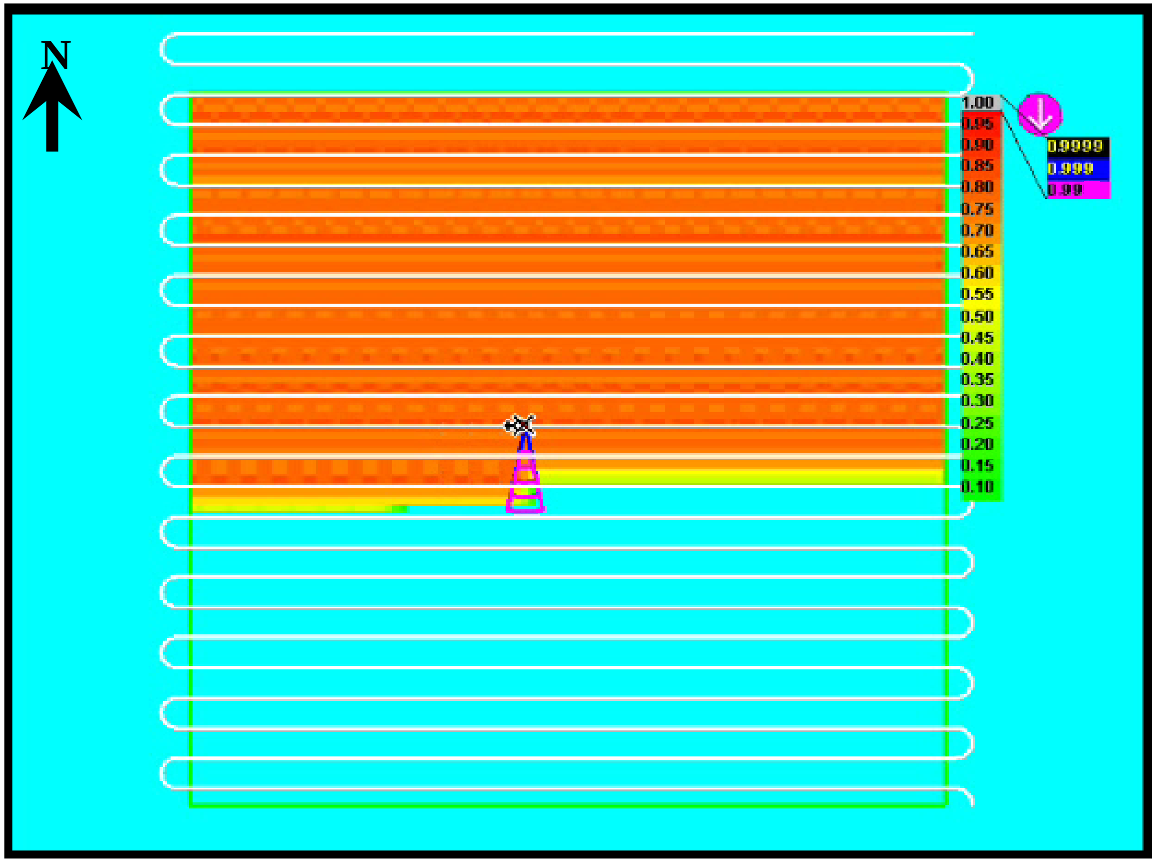



**5x5 Search Box, Small Target, 14º tilt, 500 feet altitude**
**100 knots, Track Spacing 5.5 NM, 0.3 nm track spacing**

# Good Search (Fixed Forward)

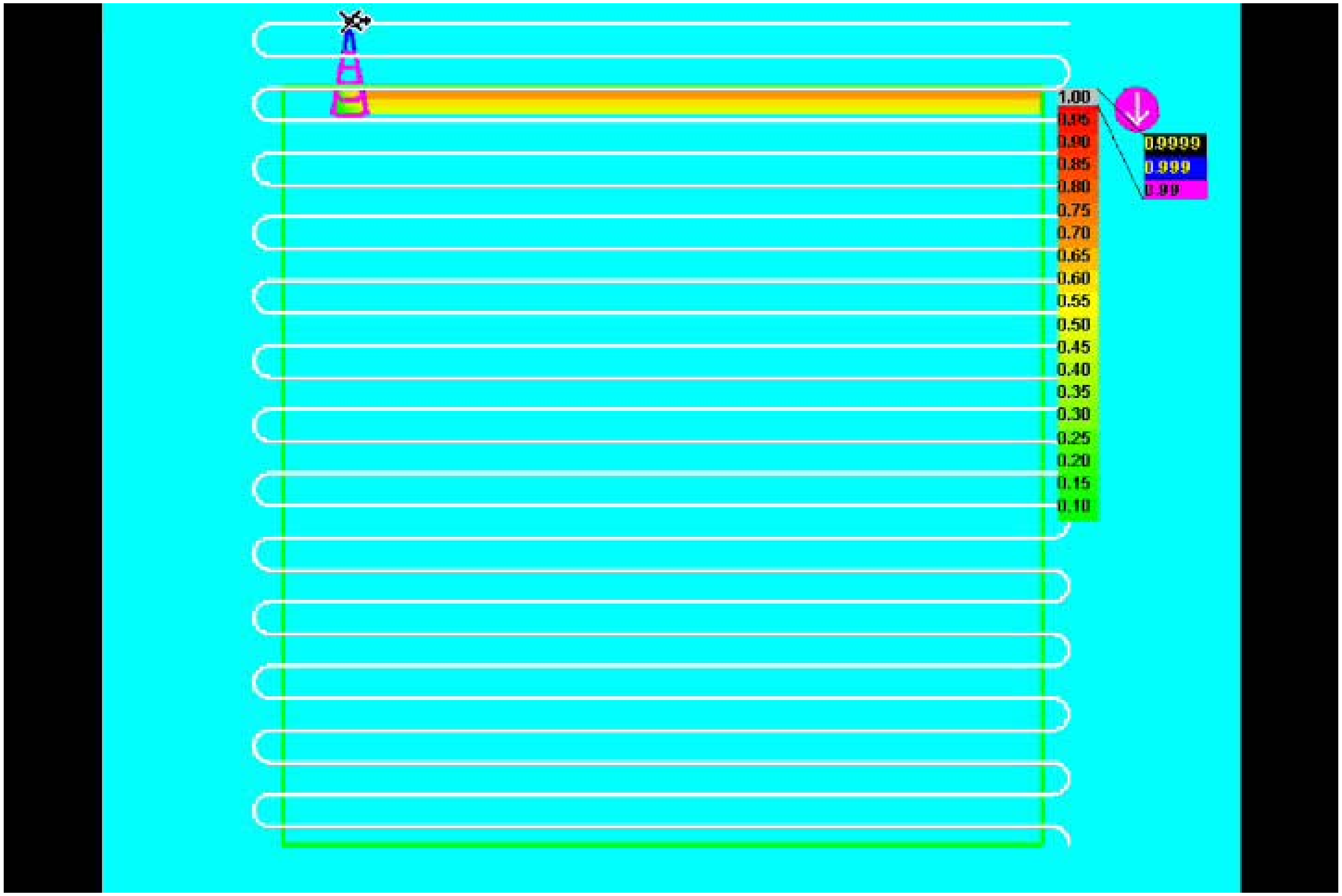


# Good Search (Fixed South)




**5x5 Search Box, Small Target, 14º tilt, 500 feet altitude**
**100 knots, Track Spacing 5.2 NM, 0.4 nm track spacing**

# Good Search (Fixed Direction)



# Parametric Analysis

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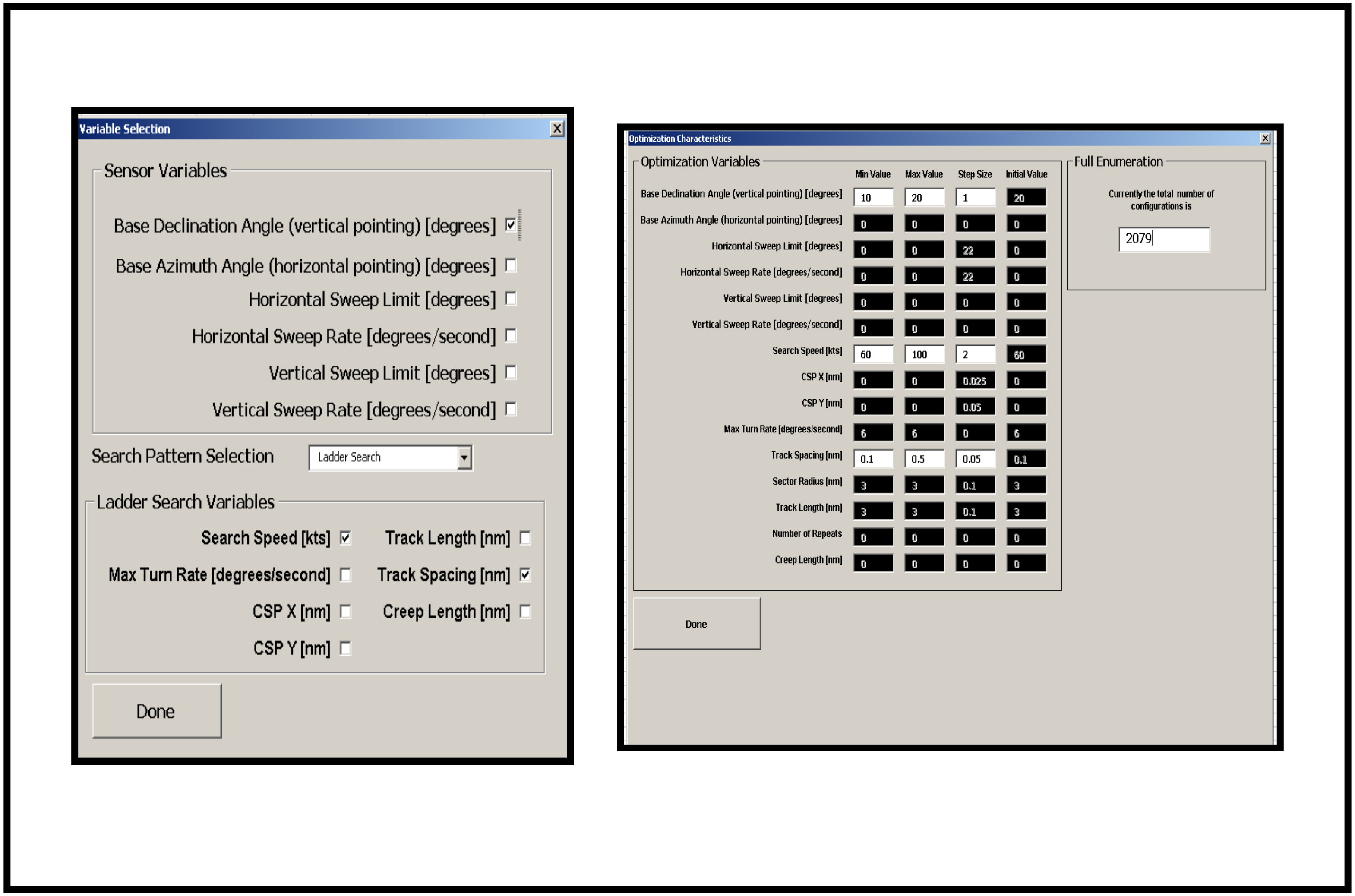
# Variable Selection

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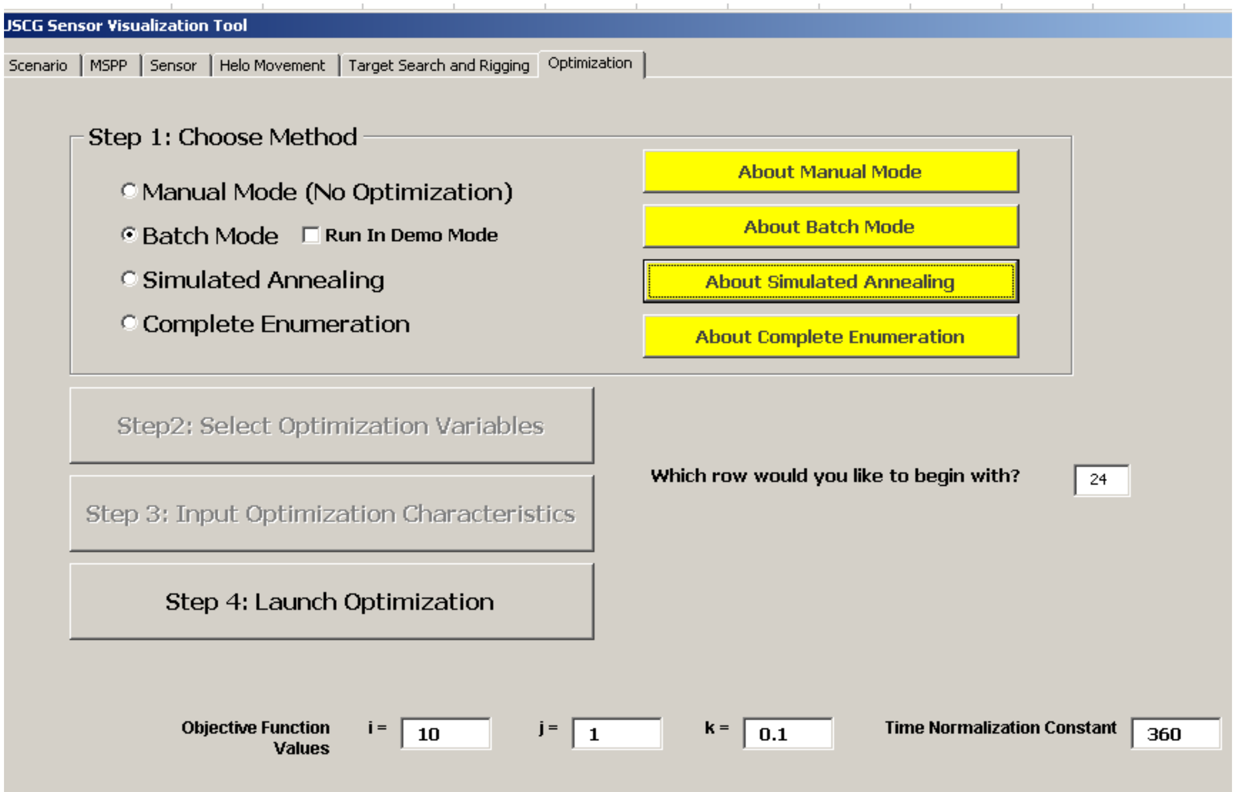
# Optimization Inputs



# Put the Computers to Work!

# Final Results (Unsorted)*

| Search Configuration Index | Declination (Tilt) [degrees] | Speed [knots] | Track Spacing [nm] | SP⊚T Score [no units] | Area (A) [no units] | Quality (Q) [no units] | Time (T) [minutes] | POD [no units] |
|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 60 | 0.1 | 0.5096 | 0.9903 | 0.3998 | 12.0033 | 0.3959 |
| 2 | 10 | 60 | 0.2 | 0.9646 | 1.0000 | 0.7420 | 26.1067 | 0.7420 |
| 3 | 10 | 60 | 0.3 | 1.1603 | 1.0000 | 0.9214 | 35.9000 | 0.9214 |
| 4 | 10 | 60 | 0.4 | 1.1947 | 1.0000 | 0.9781 | 48.6800 | 0.9781 |
| 5 | 10 | 60 | 0.5 | 1.1931 | 1.0000 | 0.9945 | 58.2767 | 0.9945 |
| 6 | 10 | 60 | 0.6 | 1.1777 | 1.0000 | 0.9986 | 69.1833 | 0.9986 |
| 7 | 12 | 60 | 0.1 | 1.2617 | 0.9998 | 0.9608 | 23.1367 | 0.9606 |
| 8 | 12 | 60 | 0.2 | 1.2307 | 1.0000 | 0.9994 | 44.9033 | 0.9994 |
| 9 | 12 | 60 | 0.3 | 1.1772 | 1.0000 | 1.0000 | 70.4267 | 1.0000 |
| 10 | 12 | 60 | 0.4 | 1.1413 | 1.0000 | 1.0000 | 95.9767 | 1.0000 |
| 11 | 12 | 60 | 0.5 | 1.1146 | 1.0000 | 1.0000 | 121.6433 | 1.0000 |
| 12 | 12 | 60 | 0.6 | 1.0959 | 1.0000 | 1.0000 | 144.0567 | 1.0000 |
| 13 | 14 | 60 | 0.1 | 0.9577 | 0.9813 | 0.9223 | 37.4333 | 0.9051 |
| 14 | 14 | 60 | 0.2 | 1.1554 | 1.0000 | 0.9945 | 80.3467 | 0.9945 |
| 15 | 14 | 60 | 0.3 | 1.1152 | 1.0000 | 0.9997 | 120.5367 | 0.9997 |
| 16 | 14 | 60 | 0.4 | 1.0817 | 1.0000 | 1.0000 | 164.0600 | 1.0000 |
| 17 | 14 | 60 | 0.5 | 1.0584 | 1.0000 | 1.0000 | 204.1233 | 1.0000 |
| 18 | 14 | 60 | 0.6 | 1.0384 | 1.0000 | 1.0000 | 247.0333 | 1.0000 |
| 19 | 16 | 60 | 0.1 | 0.9229 | 0.9998 | 0.7710 | 58.4467 | 0.7709 |
| 20 | 16 | 60 | 0.2 | 1.0605 | 1.0000 | 0.9502 | 120.0833 | 0.9502 |
| 21 | 16 | 60 | 0.3 | 1.0575 | 1.0000 | 0.9894 | 184.9033 | 0.9894 |
| 22 | 16 | 60 | 0.4 | 1.0365 | 1.0000 | 0.9977 | 245.8467 | 0.9977 |
| 23 | 16 | 60 | 0.5 | 1.0148 | 1.0000 | 0.9996 | 309.6667 | 0.9996 |
| 24 | 16 | 60 | 0.6 | 0.9999 | 1.0000 | 0.9999 | 360.0067 | 0.9999 |
| 25 | 18 | 60 | 0.1 | 0.5572 | 0.9802 | 0.5880 | 83.4033 | 0.5763 |
| 26 | 18 | 60 | 0.2 | 0.8901 | 1.0000 | 0.8258 | 170.1800 | 0.8258 |
| 27 | 18 | 60 | 0.3 | 0.9602 | 1.0000 | 0.9291 | 258.8733 | 0.9291 |
| 28 | 18 | 60 | 0.4 | 0.9751 | 1.0000 | 0.9707 | 344.0733 | 0.9707 |
| 29 | 18 | 60 | 0.5 | 0.4914 | 1.0000 | 0.4373 | 112.1167 | 0.4373 |
| 30 | 18 | 60 | 0.6 | 0.7106 | 1.0000 | 0.6795 | 229.9533 | 0.6795 |
| 31 | 20 | 60 | 0.1 | 0.8196 | 1.0000 | 0.8157 | 343.3267 | 0.8157 |
| 32 | 20 | 60 | 0.2 | 0.3595 | 0.9900 | 0.3628 | 144.2800 | 0.3592 |
| 33 | 20 | 60 | 0.3 | 0.6094 | 1.0000 | 0.5970 | 293.1367 | 0.5970 |
| 34 | 20 | 60 | 0.4 | 0.3633 | 0.9900 | 0.3754 | 183.2767 | 0.3717 |
| 35 | 20 | 60 | 0.5 | 0.6046 | 1.0000 | 0.6046 | 360.0067 | 0.6046 |
| 36 | 20 | 60 | 0.6 | 0.3967 | 0.9900 | 0.4179 | 221.9200 | 0.4137 |

- 
- ***180 total search configurations***
- 

* *Notional Data - For illustrative purposes only*

# Operational Analysis

# Sorted Results

**Potential Operational Considerations**

- **Maintain high POD**
- **Wider versus Narrow track spacing**
- **Pilots' favorite search speed**
- **Mission time versus survivability estimates**
- **Opportunity for counter-detection and alert from target (SAR missions only).**

| Search Configuration Index | Declination (Tilt) [degrees] | Speed [knots] | Track Spacing [nm] | SP◎T Score [no units] | Area (A) [no units] | Quality (Q) [no units] | Time (T) [minutes] | POD [no units] |
|---|---|---|---|---|---|---|---|---|
| 122 | 14 | 90 | 0.2 | 1.2719 | 1.0000 | 0.9779 | 25.9867 | 0.9779 |
| 84 | 12 | 80 | 0.6 | 1.2697 | [illegible] | [illegible] | [illegible] | [illegible] |
| 7 | 12 | 60 | 0.1 | 1.2617 | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | 70 | 0.4 | 1.2564 | 1.0000 | 0.9965 | 35.4667 | 0.9965 |
| [illegible] | [illegible] | 90 | 0.3 | 1.2393 | 1.0000 | 0.9966 | 40.7100 | 0.9966 |
| [illegible] | [illegible] | 60 | 0.2 | 1.2307 | 1.0000 | 0.9994 | 44.9033 | 0.9994 |
| [illegible] | [illegible] | 80 | 0.1 | 1.2254 | 1.0000 | 0.9989 | 46.6400 | 0.9989 |
| 45 | 12 | 70 | 0.3 | 1.2203 | 0.9972 | 0.9263 | 17.2700 | 0.9237 |
| 82 | 12 | 80 | 0.4 | 1.2093 | 1.0000 | 0.9837 | 45.6767 | 0.9837 |
| 43 | 12 | 70 | 0.1 | 1.2087 | 1.0000 | 0.9827 | 45.4400 | 0.9827 |

**Operationally Favorable Track Spacing**

**Highest SPOT Score**

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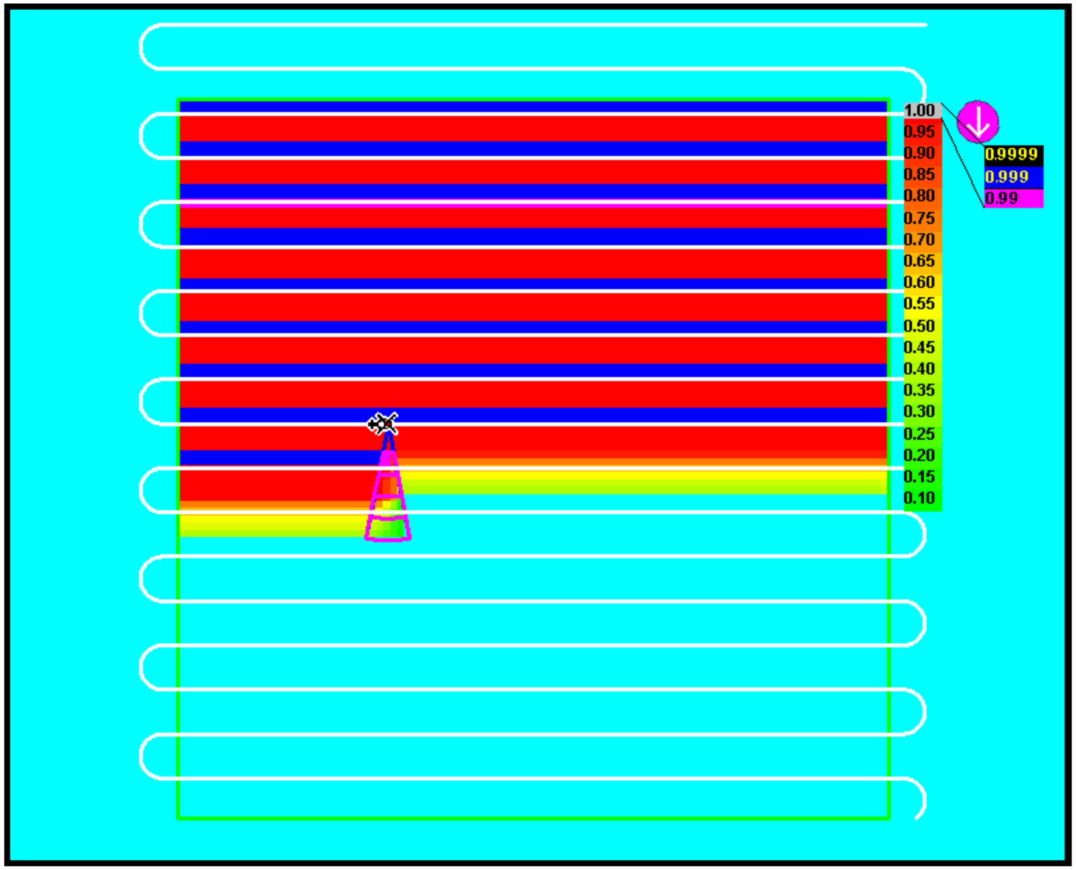
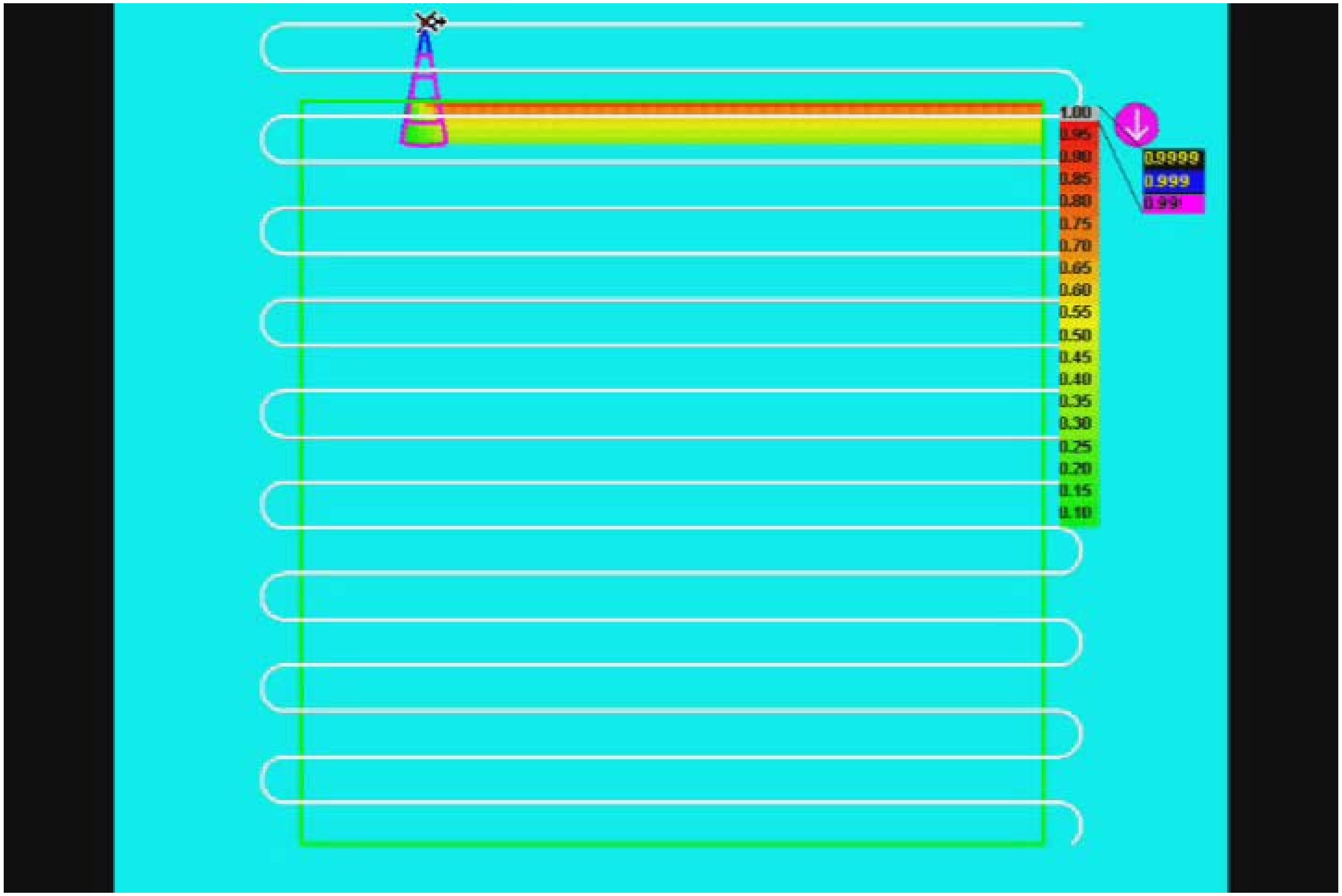
# Selected Run




5x5 Search Box, Small Target, 14° tilt, 500 feet altitude
100 knots, Track Spacing 5.2, 0.6 nm track spacing

# Selected Run



# Key Takeaways

- **The ability to visualize search effectiveness is a powerful aid to search planners and analysts.**
- **The project reveals a need for metrics beyond POD and other traditional measures.**
- **IR-based sensor systems show promise as primary detection devices.**

# Acknowledgements

- **About the Authors**
  - *William Lyle* **is the Program Manager and Principal Analyst for SPA's M&S-Based Analysis Support to the RDC.**
  - *James Richardson* **is a Senior Operations Research Analyst with SPA.**
  - *Kevin Downer* **is a Senior Operations Research Analyst at the USCG RDC.**
- **Acknowledgments**
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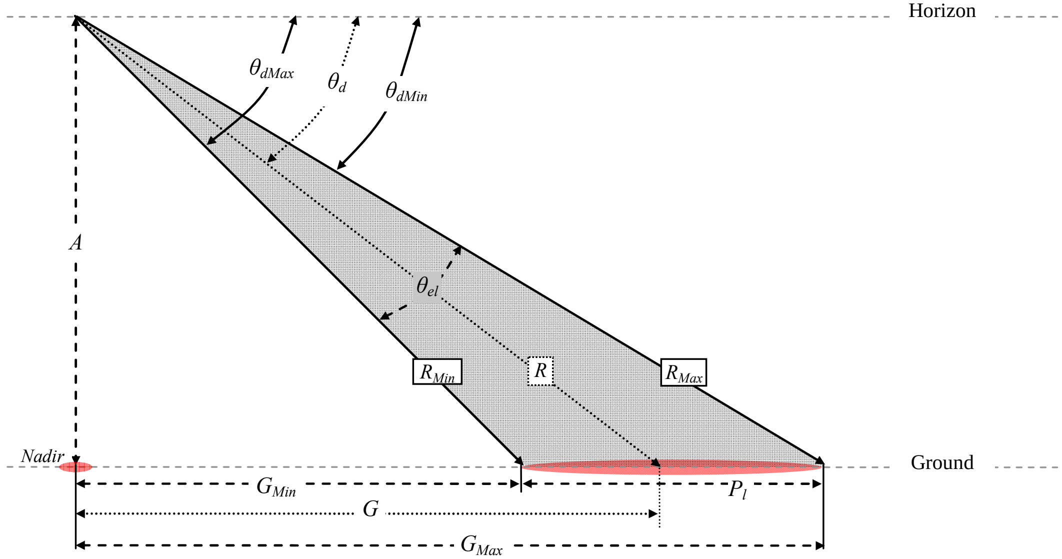
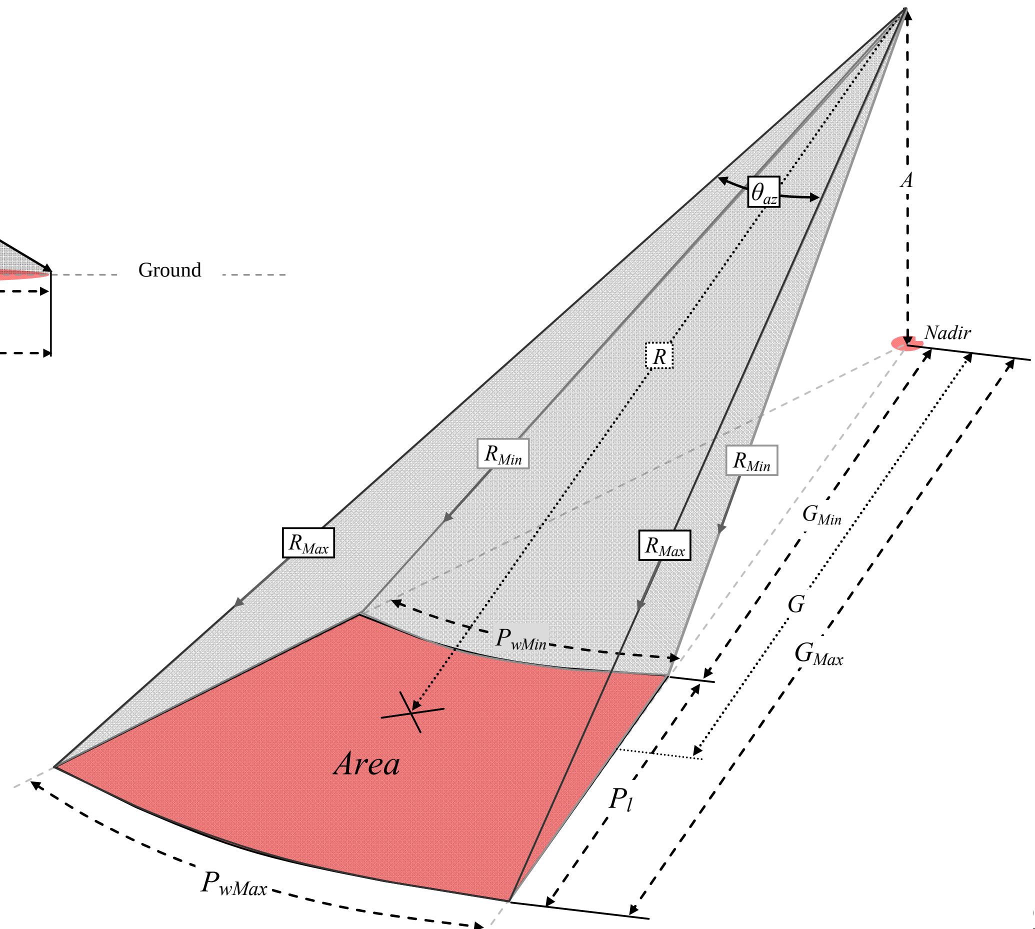
  - **The authors would like to further acknowledge the key contributions of various organizations within the USCG and their staff – whose participation helped put the word "resounding" in the phrase "resounding success" for the project:**
    - **Staff scientists at the USCG RDC – who helped substantially with the validation efforts.**
    - **The flight mechanics and pilots at AR&SC Elizabeth City, ATC Mobile, and Clearwater Air Station – who helped keep the entire team on solid operational footing.**

# General Backup

# Pointing Sensor Basics



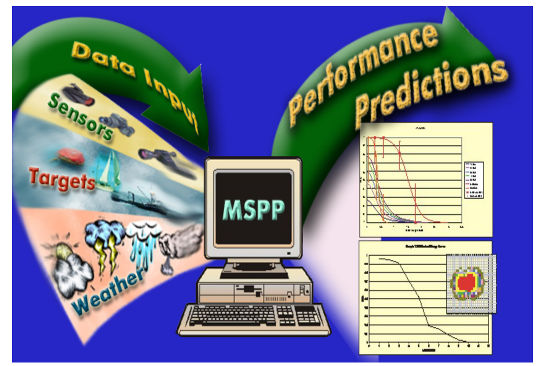

Where: $A \equiv$ Altitude
- $R \equiv$ Slant Range (centered in FOV)
- $R_{Min} \equiv$ Minimum Slant Range (seen from bottom of FOV)
- $R_{Max} \equiv$ Maximum Slant Range (seen from top of FOV)
- $\theta_{el} \equiv$ FOV in Elevation
- $\theta_{az} \equiv$ FOV in Azimuth
- $\theta_d \equiv$ Turret Depression Angle (from horizon to center of FOV)
- $\theta_{dMin} \equiv$ Turret Depression Angle (from horizon to top of FOV)
- $\theta_{dMax} \equiv$ Turret Depression Angle (from horizon to bottom of FOV)
- $G \equiv$ Distance from Nadir to Center Ground Point in FOV
- $G_{Min} \equiv$ Distance from Nadir to Nearest Ground Point in FOV
- $G_{Max} \equiv$ Distance from Nadir to Furthest Ground Point in FOV
- $P_l \equiv$ Ground Projection Length
- $P_{wMin} \equiv$ Ground Projection Width at Nearest Point in FOV
- $P_{wMax} \equiv$ Ground Projection Width at Furthest Point in FOV

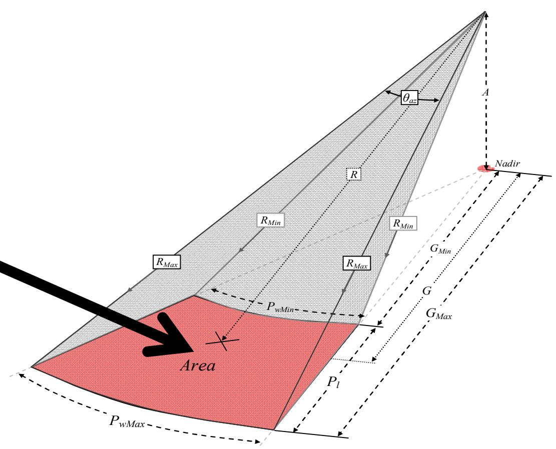
# Multi-Sensor Performance Prediction (MSPP)

***A VALIDATED SOFTWARE TOOL THAT ASSISTS ANLYSTS IN PREDICTING SENSOR PERFORMANCE FOR CG MISSIONS***

## Gridded POD Output from MSPP

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 7 | 10 | 7 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 2 | 8 | 45 | 28 | 4 | 7 | 44 | 75 | 77 | 72 | 42 | 7 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 2 | 15 | 76 | 78 | 71 | 25 | 29 | 92 | 97 | 95 | 90 | 78 | 61 | 6 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 9 | 86 | 93 | 97 | 97 | 85 | 97 | 100 | 100 | 100 | 98 | 90 | 75 | 31 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 3 | 31 | 94 | 98 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 96 | 84 | 64 | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 5 | 62 | 97 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 98 | 89 | 69 | 10 | 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 6 | 73 | 98 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 98 | 89 | 69 | 11 | 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 5 | 63 | 97 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 97 | 85 | 64 | 8 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 3 | 34 | 95 | 98 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 99 | 92 | 73 | 51 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 1 | 11 | 90 | 95 | 98 | 98 | 94 | 86 | 100 | 100 | 99 | 92 | 75 | 54 | 14 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 3 | 22 | 86 | 89 | 86 | 66 | 26 | 62 | 82 | 78 | 66 | 49 | 35 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 1 | 3 | 14 | 68 | 58 | 32 | 11 | 6 | 25 | 33 | 32 | 9 | 2 | 0 | 0 | 0 | [illegible] | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 5 | 3 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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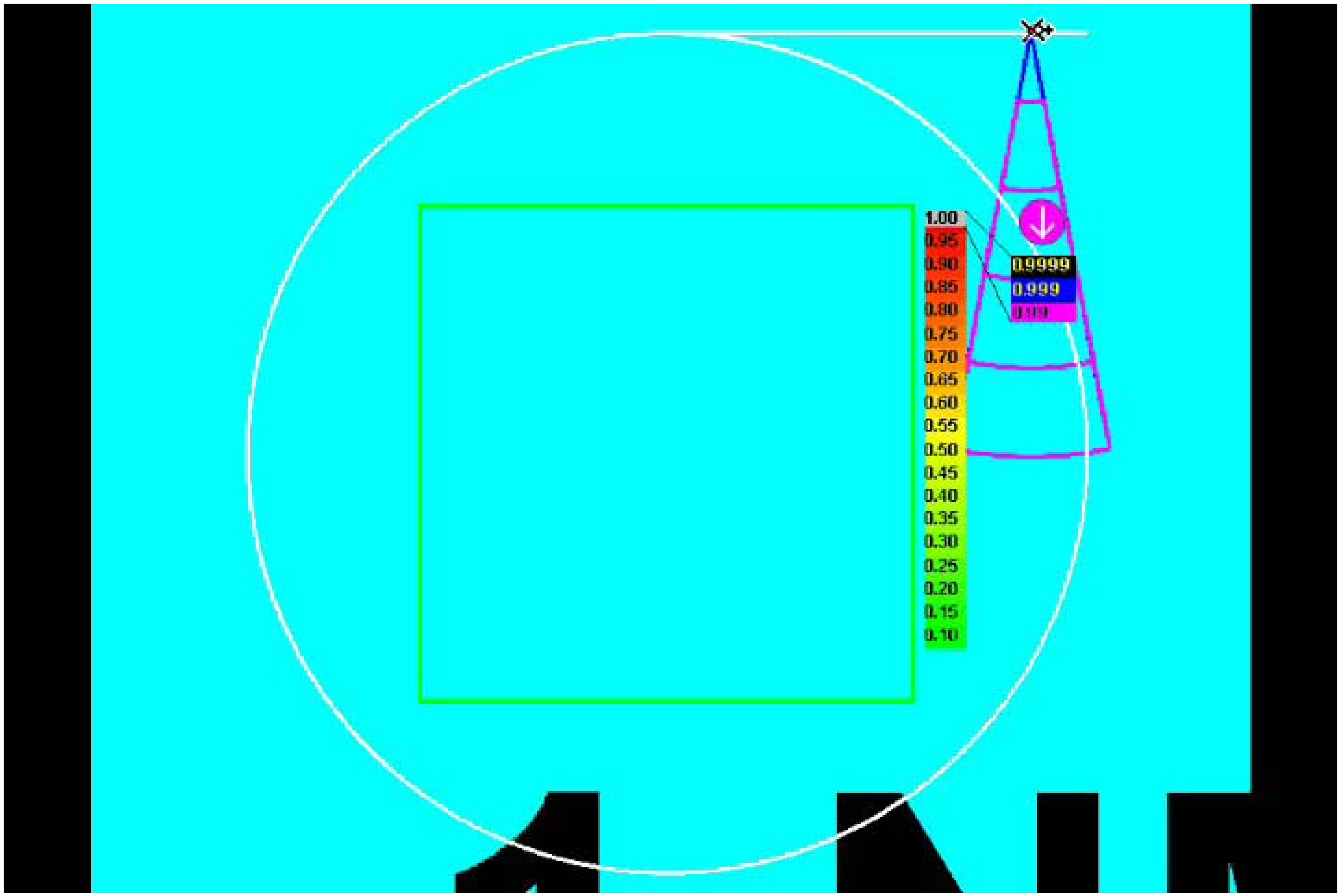
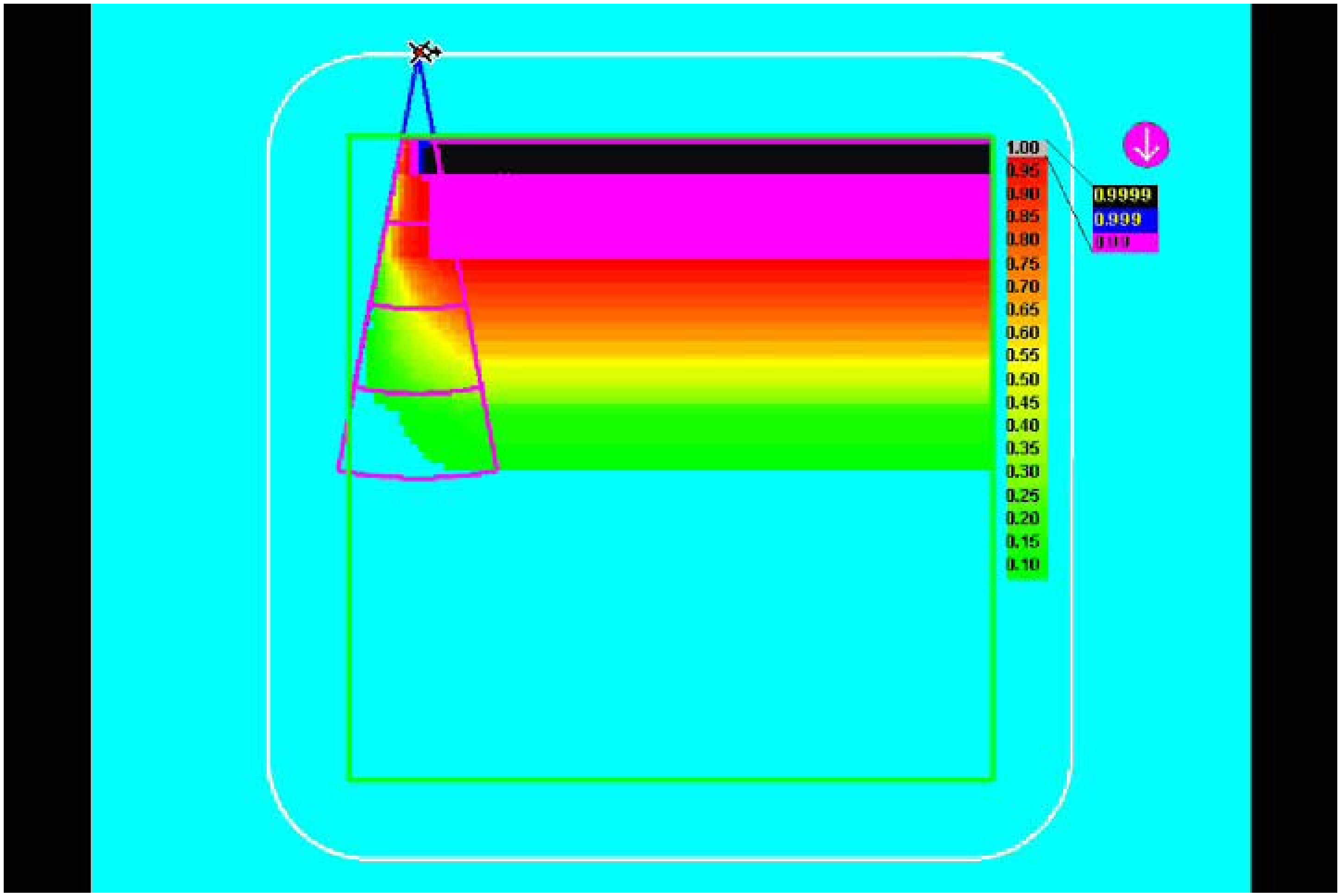
# Exotic Circle



# Rounded Square

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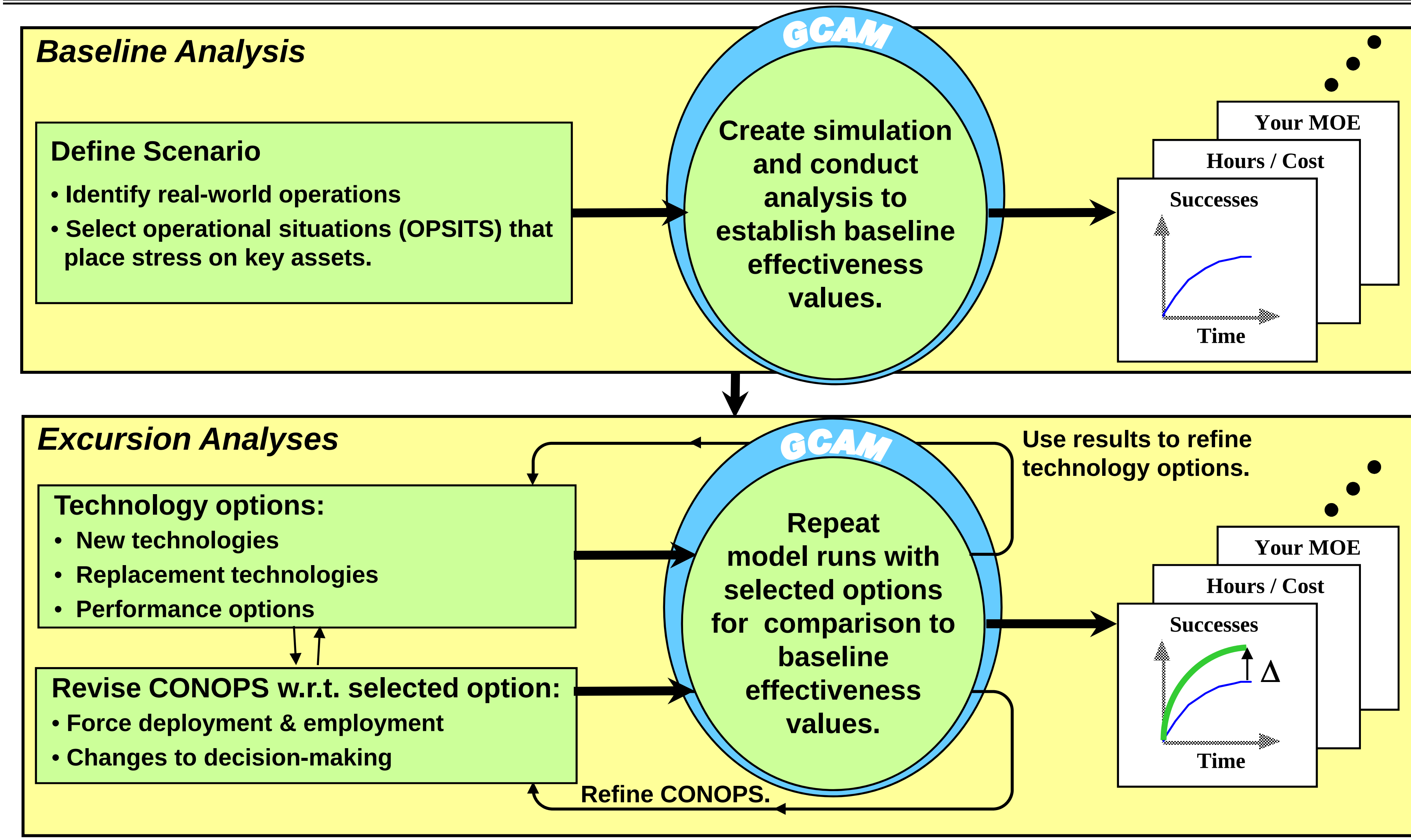
# More about GCAM

# Modeling, Simulation, and Analysis Approach



# Key GCAM Capabilities

- Support rapid development and execution of M&S projects
- Provide flexibility to …
  - Employ PCs
  - Use available data with little reformatting
  - Set resolution to match analysis requirements
  - Mix scripted with stochastic behaviors
  - Match operational tempo to required antecedents
    - E.g. actionable intelligence, weapons/platforms availability, …
  - Endow objects with critical decision-making functionality
  - Capture entire hierarchy of MOEs/MOPs
- Leverage large, talented user base – since 1995
- Integrate cutting-edge M&S with military experience and expertise

# The GCAM Core Tool Suite Technical Overview